EFFECTS OF TASK-LEVEL LANGUAGE INPUT ON BILINGUAL COGNITIVE ADVANTAGE

A Thesis

Presented to

The Faculty of the Department

of Psychology

University of Houston

In Partial Fulfillment

Of the Requirements for the Degree of

Master of Arts

By

Grace E. Cannon

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ABSTRACT

Bilingualism—through learning and speaking two languages—has been considered to contribute to the development of enhanced cognitive control, including attention, inhibition, and switching. Theories, experimental work, and models suggest that both languages are always activated, and that creates a greater need for conflict processing, yet exactly how this cognitive demand is tightly coupled with one's language processing is not fully understood. The current study aims to establish a cohesive view of cognitive control in bilingual and monolingual individuals at a crucial stage in cognitive development during early childhood. By altering the degree of lexical access required during the card sorting paradigm requiring rule-switching, the study attempts to address prior gaps in knowledge of the relationship between bilingualism and the mechanisms of language and cognitive control. Results suggest that bilingual advantages were prominent only when pictures were novel, where no activation of a corresponding label is expected. In contrast, monolinguals showed an advantage when pictures were familiar and sorted semantically, where activation of the corresponding lexical concept is expected. Children also demonstrated the best performance overall on the semantic task with only visual input, whereas they showed the largest switch costs on the semantic condition with both visual and spoken input. Here, we demonstrate that bilingual advantages are not demonstrated on language-based tasks regardless of spoken labels, but a bilingual disadvantage occurs on a visual semantic task with high demands for lexical access. Findings suggest that the bilingual advantage is heavily dependent on lexical access demands.

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Cognitive control involves the ability to update goal-oriented information in working memory, shift the focus of attention, and inhibit distracting or irrelevant stimuli (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). Bilingual children need to learn two sets of linguistic systems that can generate conflicting rules at an early age, and this experience may contribute to the development elements of cognitive control including attentional control, inhibition, and switching. In order to learn multiple sets of linguistic rules properly, inhibition is needed to suppress the properties of one language while hearing and speaking the other (Bialystok et al., 2005). Switching between the two languages in appropriate situations according to their contextual knowledge is also required (Abutalebi & Green, 2008). Bilingual studies indicate that both languages are always activated, creating a greater need for conflict processing (Abutalebi & Green, 2007; Colomé, 2001). These excess language demands are thought to contribute to bilingual advantages found in cognitive control (see Akhtar & Menjivar, 2012, for review).

Bilingual children have been shown to enjoy advantages in certain language tasks as well. For example, bilingual children perform better on metalinguistic tasks such as phonological awareness, due to their understanding that different languages use different sounds, words, and structures to refer to the same concepts (Marinova-Todd, Zhao, & Bernhardt, 2010; Bialystok, 2007). Since young bilinguals have extensive verbal and aural practice in attentional control, inhibition, and switching from using their two languages, it might be expected that they would develop advanced performance in verbal tasks of cognitive control. However, language processing in bilinguals can suffer due to interference between their two languages, possibly making verbal tasks more difficult, including tests of cognitive control (e.g., Bialystok, Craik, & Luk, 2008). The complex relationship between cognitive control performance and language processing remains poorly understood. For example, the mechanism of lexical access may provide a link between bilingual cognitive control and language processing. Lexical access is the process of retrieving the correct linguistic label for a given concept, which includes activation of possible lexical targets, competition between activated items, and selection of a response (Costa, La Heij, & Navarette, 2006; Levelt, Roelofs, & Meyer, 1999). Conflict from having twice as many words activated for one concept during lexical access can hurt bilinguals and may prevent them from showing cognitive advantages on control tasks that necessitate language processing. In fact, if the demands for lexical access are too high in a cognitive control task, bilinguals may show a *disadvantage* relative to monolinguals. However, if lexical access is the reason for bilingual difficulty in verbal cognitive control tasks, then providing children with spoken labels to reduce the demands of lexical access should improve bilingual performance.

The current study specifically examined what type of input provides the optimal environment for cognitive control performance in monolingual and bilingual children by considering the interaction between the effects of environmental language experience (e.g., bilingual vs. monolingual) and task-level language input (e.g., whether or not using familiar items for which children know the labels) on cognitive control (e.g., card-sorting task that requires switching rules). In order to establish how language input in the task environment affects cognitive control performance in monolingual and bilingual children, the current study used three variants of the Dimensional Change Card Sort (DCCS) task. Children between 4-6 years old were selected for the current study because this age group goes through rapid development in cognitive control, providing the variability where the effect of individual language experiences are expected (Roebers, Röthlisberger, Cimeli, Michel, & Neuenschwander, 2011; Röthlisberger, Neuenschwander, Michel, & Roebers, 2010).

Varied results in bilingual cognitive differences

Recent studies on bilingual advantages in cognitive control have produced mixed results (Kovacs & Mehler, 2009; Morales, Calvo, & Bialystok, 2013; Prior & MacWhinney, 2010; Bialystok, Craik, & Luk, 2008; Engel de Abreu, 2011; Namazi & Thordardottir, 2010; Blom, Küntay, Messer, Verhagen, & Leseman, 2014; Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011). However, these experiments have used a wide range of tasks that include varying degrees of language processing without necessarily accounting for task-specific effects of language use. Both linguistic and non-linguistic tests of cognitive control have demonstrated a bilingual advantage in young children (Bialystok, 1999; Bialystok, Martin, & Viswanathan, 2005), but results in linguistic tasks are far less consistent (e.g., Martin-Rhee & Bialystok, 2008; Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011). One reason may be the variability in task-level language input and information (e.g. semantic value, spoken word labels) across studies. As noted above, lexical access may provide the mechanism that influences this variability. When familiar visual stimuli are presented, bilinguals must cope with more lexical activations (e.g., two labels). In this framework, bilinguals' advantage might be most pronounced when no semantic information is provided, thus reducing lexical activations in both monolinguals and bilinguals. Additionally, monolinguals may show advantages when presented with semantic input without labels, since they only generate one set of lexical activations. These novel predictions are tested in the current study.

Evidence from cognitive control tasks with language processing. Language-related aspects of cognitive processing that are sometimes not considered in control tasks include information presented aurally, the extent to which stimuli have semantic value, and item labels (Bialystok, 2011; Kovács & Mehler, 2009). For example, in a coordination task requiring verbal responses to non-speech auditory cues and motor responses to simultaneous visual cues, bilingual children were more accurate than monolingual children in sorting stimuli based on semantic categories (Bialystok, 2011). Within the coordination task, trends indicated that bilinguals performed better on the visual-motor task compared to the auditory-verbal task. The diminished auditory advantage may have been due to the response requirement to retrieve and select the appropriate word in the correct language, but the effects of response could not be teased apart from the effects of cue type in this experiment. This represents a failure to consider the influence of aurally presented information, which may share more neural information pathways with speech input (compared to visual information), thus potentially creating similar bilingual difficulties in processing (Zaehle, Wüstenberg, Meyer, & Jäncke, 2004). In the current study, only motor responses were required, and speech stimuli were used to provide a direct link to the correct language, enabling us to evaluate precisely how the task-level language input—rather than responses—affects cognitive control.

Bilingual advantages in both visual and auditory cognitive control were demonstrated in preverbal 7-month-old infants with bilingual exposure, who performed switching tasks with either geometric shapes or speech-like auditory cues (Kovács & Mehler, 2009). In these tasks, infants were exposed to patterns of either speech-like auditory cues consisting of three different syllables, or sets of three basic shapes. Both monolingual and bilingual infants were conditioned to look at one side of a screen toward an expected visual reward. When the target reward switched to the other side of the screen, only bilinguals changed their looking to the new reward. However, the bilingual advantage with speech-like cues may only occur in such young children because they do not have any semantic values to assign to the sounds and are too young to associate them with lexical items, thus eliminating potential language interference. This demonstrates a bilingual advantage using auditory stimuli, but it does not provide conclusive evidence for bilingual advantage on cognitive control tasks with language processing.

In one study with 24-month-old children, bilinguals did demonstrate a cognitive advantage on a language-based task (Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011). On three tasks that measured conflict resolution, only a Shape Stroop task showed a bilingual advantage. In this task, pictures of small fruits and large fruits were labeled, and then children had to point to the correct small fruit named by the experimenter while viewing pictures of the small fruits inside conflicting large fruits. The spoken labels may have reduced lexical access demands for bilinguals enough to overcome the difficulty of processing twice as many lexical activations from the familiar images of fruits in the Shape Stroop task. Children also performed a multilocation task where they were asked to find an item hidden in one of three drawers after it was moved from its original position, and they performed a reverse categorization task where they were asked to sort small blocks into big buckets and big blocks into small buckets. In contrast to the Shape Stroop task, the multilocation task with hidden items was not related to semantic input, as all three possible locations were simply labeled "here." Also, a reverse categorization task with small blocks sorted into big buckets and big blocks sorted into small buckets required categorization by perceptual, not semantic, features. Neither of these tasks showed a bilingual advantage, but they also were structurally different from the Shape Stroop task in many ways other than the semantic and linguistic input provided. The multilocation task in particular was also too difficult for many of the children tested according to Poulin-Dubois and colleagues. To resolve extraneous discrepancies between tasks, the current study used cognitive control tasks that follow the same procedures but differed in the types of stimuli being presented, providing comparable scores to appropriately test the influence that the task-level language input has on cognitive control performance.

In contrast, Martin-Rhee and Bialystok (2008) did not find a bilingual advantage on a language-based test of cognitive control in 5-year-old children. In this study, they compared a nonlinguistic Simon task (e.g., responding to a visual cue based on color, requiring inhibition when the spatial location does not correspond to the location of the required motor response) and Stroop Picture-Naming task, which required children to say the opposite label for a given picture (e.g. "day" for a picture of the moon, or "night" for a picture of the sun). Bilingual children performed better than monolingual children on the nonlinguistic Simon task, but not on the Stroop Picture-Naming task. The authors speculated that the bilinguals only demonstrate advantages on the Simon task and not the Stroop task due to different mechanisms of cognitive control, without considering the involvement of language processing.

They suggest that the bilingual advantage on the Simon task stems from heightened attentional control, but they also propose that the lack bilingual advantage on the Stroop task meant that bilinguals do not have enhanced inhibitory control. However, established evidence showing bilingual advantages in inhibitory control suggests that the bilingual performance on the Stroop task might be better explained another way (e.g. Hilchey & Klein, 2011). Instead, this difference could be due to the two sets of activations occurring for bilinguals when trying to name the correct item in the Stroop task, which may make the task more demanding for bilinguals compared to monolingual children. The current study specifically tested this very idea by keeping the task procedures equivalent and carefully manipulating the need for language processing within each condition.

Bilingual cognitive advantages on nonsemantic tasks

As opposed to linguistic tasks, the bilingual advantage has been documented more robustly in tasks that do not require language processing (Akhtar & Menjivar, 2012). Hilchey and Klein (2011) pointed out that bilingual children as well as adults typically show advantages on nonlinguistic tasks requiring conflict processing, such as the standard Simon task, the spatial Stroop task, and the flanker task, which all require judgments of visuospatial stimuli (e.g. arrow, geometrical shape) based on visual perceptual features (e.g. direction of arrow, location on screen) with a motor response (e.g. button press; Bialystok, Martin, & Viswanathan, 2005; Carlson & Meltzoff, 2008; Martin-Rhee & Bialystok, 2008; Morton & Harper, 2007; Luk, De Sa, & Bialystok, 2011). This type of task does not require lexical access in order to select a correct response. This suggests that as long as lexical access is not involved in the task, bilinguals can demonstrate their enhanced cognitive skills, since they are not hurt by the additional cognitive demand of lexical selection from two sets of linguistic possibilities.

Similarly, bilingual advantages emerge in a nonlinguistic rule-switching paradigm, which could also be modified to involve language processing. Monolingual English and bilingual adults were tested on a computerized task-switching paradigm, where the rules changed based on visual cues (Prior and MacWhinney, 2010). Each trial presented a visual cue before a target object on screen, both of which were specifically designed to eliminate linguistic influence. The targets were red or green circles and triangles. The cue was either a color gradient, which would tell the participant to sort by color, or a row of black shapes, which would tell the participant to sort by shape. The trials used for analysis were mixed so that adjacent trials would switch randomly between sorting by color and sorting by shape. Their results showed that bilinguals responded faster than monolinguals on switching trials (but the same in non-switching trials), indicating that bilinguals have a cognitive advantage in switching. Consistent with these findings, the current study predicts a bilingual advantage on a similar nonsemantic switching task, the Dimensional Change Card-Sorting task (DCCS; Frye, Zelazo, & Palfai, 1995), which is designed for children. Using familiar visual images and spoken labels, the current study tested the influences of semantic and linguistic information on bilingual cognitive advantages. By comparing a nonsemantic task to a semantic task while providing the same type of input (visual), we can examine how the added semantic value affects bilingual advantages due to the need for language processing. Then by comparing semantic tasks with different types of input (visual and speech), we can study how added lexical input may provide bilingual children with a specific language context, which may provide bilinguals with reduced demands for language processing.

Dimensional change card-sorting as a measure of cognitive control

The most established findings of cognitive advantages in bilingual children are on the dimensional change card-sorting task (Bialystok, 1999; Carlson & Meltzoff, 2008). The standard version of DCCS, originally developed by Frye, Zelazo, and Palfai (1995), assesses performance on a rule-switching task, which require subjects to sort a set of stimuli first based on one featural dimension (e.g. shape) in a *preswitch* block, and then based on a second featural dimension (e.g. color) in a *postswitch* block. Children are generally expected to succeed on the preswitch block of the DCCS task as young as three years old. Children generally do poorly on the postswitch block until they are four years old, when most children switch rules correctly (Zelazo, 2006). An advanced version of DCCS assesses performance on a *mixed* block using the same set of stimuli and a secondary visual cue in each trial that determines how to sort the stimulus (for protocol, see Zelazo, 2006). In the mixed block, subjects are required to dynamically switch their attention between the two relevant dimensions. This advanced version is an appropriate measure for five-year-old children, when about half of children are expected to succeed on the mixed block (Zelazo, 2006). Previous studies have demonstrated age-appropriate performance for children—as well as significant individual differences—across DCCS tasks that require different types of sorting. This indicates that this task is appropriate for manipulating cognitive control and language processing (Coldren, 2013; Bialystok & Martin, 2004).

In one experiment testing the effects of labels, Yerys & Munakata (2006) tested three-year-old children on three DCCS tasks. The conditions tested the effect of explicitly labeling item categories for familiar items, as well as labeling unfamiliar items with novel labels. This study used familiar images and labels to manipulate representational complexity but did not relate their findings to lexical access or consider the possible effects of this input on the bilingual advantage. The results showed that children performed better with both the unlabeled familiar objects and the novel labeled objects, compared to the familiar labeled objects. The authors suggest that familiar labels could be detrimental to young children's cognitive control, since the labels may restrict children's thinking to a single rule, reducing their ability to switch. It is not known whether labels would remain detrimental or become more helpful for 4- to 6-year-old children as they develop cognitive and language skills. In the case of the novel labeled condition, the authors suggest that the children have fewer constraints to begin with, due to the novelty of the input. This may mean that if the visual stimuli does not have any semantic value—meaning that it has no known label—then fewer possible responses are activated, thus reducing cognitive interference. However, all conditions in this experiment were sorted by their perceptual features. This may be because lexical access was not required for any semantic meaning. The current study investigated whether the increase in activations on a semantic task causes bilingual and monolingual children to respond differently when processing information visually and aurally. Unlike Yerys and Munakata, the labels used in this study do not correspond directly to the categories used for the sorting rules. Instead, the item labels provide a semantic link to the correct category, either the type of item or the color of the item, which helps activate the correct responses, and may help bilinguals select only one language.

While the bilingual advantage has been established in multiple studies with DCCS, one study tested monolingual and bilingual children on both perceptual and semantic conditions. Bialystok and Martin (2004) investigated the possibility that the bilingual advantage in DCCS stems from a more mature representational system by testing monolingual and bilingual four-year-old preschool children on DCCS conditions that varied the representational complexity of the stimuli. In this case, the bilingual children showed an advantage on conditions in which sorting occurred based on perceptual, not semantic, dimensions. The authors concluded that these results occurred due to a bilingual advantage in conceptual inhibition, but the semantic tasks provided concepts that required overly complex representations, which eliminated that advantage. However, since no labeling was used in the previous study, the results might also be explained by increased language processing demands on the semantic tasks. Furthermore, the children in this study were younger (monolingual M=4;2 years, bilingual M=4;4 years), so they may have had difficulty understanding the categories used, which included functional use (toys or clothes) and locational use (inside or outside). The current study used 4-6 year olds, and high frequency items from familiar categories—foods and animals—to facilitate categorization in the semantic tasks. In this context, children should perform well enough on all DCCS conditions in order to show effects of language groups across varying levels of language input.

Bilingual disadvantages in lexical access

As discussed, bilingual advantages in cognitive control arise from the process of acquiring two languages, which generates more switching experiences between languages (Garbin et al., 2010). However, the same language experiences also diminish bilingual performance on language-related tasks by increasing conflict during language processing, due to the activation of two sets of linguistic items. For example, when bilingual children see a picture, such as an apple, they have two words that are activated instead of only one. This can cause speech errors and slow down language production (Gollan, Montoya, Fennema-Notestine, & Morris, 2005). This causes bilinguals to show poorer lexical access than monolinguals across development and in both of their languages (Ivanova & Costa, 2008; Pelham & Abrams, 2014; Poulin-Dubois, Bialystok, Blaye, Polonia, & Yott, 2012; Yan & Nicoladis, 2009). The tasks used to test such lexical access are specific to speech production (i.e., picture naming) and their relevancy to cognitive control tasks that require motor responses may not be obvious. However, the mechanisms of lexical access may explain the variability found in the bilingual advantage on cognitive control tasks where language processing has not been considered as a factor. Established findings show that both language inhibition and language selection may be used in bilingual lexical access and have a role in selecting correct concepts and responses (Costa, Santesteban, & Ivanova, 2006; Costa et al., 1999; Costa & Caramazza, 1999; Green, 1998; Finkbeiner, Gollan, and Caramazza, 2006; La Heij, 2005). In the current study, the effect of language input on cognitive control was tested with conditions of DCCS varying in semantic value, visual input, and speech input to find out how bilingual lexical access may negatively affect cognitive control when language processing is required for a semantic task, and how spoken labels may improve bilingual performance by reducing lexical access demands.

The current study: testing bilingual differences across language input conditions

The current study aims to establish a cohesive view of cognitive control in bilingual and monolingual individuals at a crucial stage in development, as their cognitive abilities are rapidly changing. By testing the same cognitive control paradigm with varying degrees of lexical and semantic input, this study attempts to address prior gaps in knowledge of the relationship between bilingualism and the mechanisms of language and cognitive control. One possibility for to explain differences among cognitive control tasks is that bilingual activation of two languages interferes with covert lexical retrieval of item and category labels. If so, activating the correct lexical item in the target language should help overcome this difficulty. In that case, we would expect to see bilingual advantages on a semantic condition with spoken labels.

Hypothesis 1. Bilingual children will show greater accuracy than monolinguals on a nonsemantic task, but not on a corresponding semantic condition when given no lexical input.

Hypothesis 2. If a spoken label provides a means for bilinguals to overcome difficulties with lexical access, then bilinguals should also show greater accuracy than monolinguals on a semantic condition with labels providing lexical input.

Method

Participants

Thirty-nine children participated in the current study. Three participants were excluded from analyses, two because of reported developmental disorders, and one due to failure to complete tasks requiring verbal responses. The remaining 36 participants included in the analyses were between 54.9-80 months old (M=66.9, SD=7.4 mo). Eighteen English monolinguals (5 male; M=68.7, SD=7.5 mo) and 18 heterogeneous bilinguals (10 male; M=65.1, SD=7.0 mo) were included in the study. All bilinguals spoke English as one of their languages. Second languages were distributed as follows: Spanish (10), Mandarin (2), Arabic (1), Bahasa (1), Bengali (1), Hindi (1), Malayalam (1), and Russian (1). All children were typically developing as reported by parents, and reported to have normal or corrected-to-normal vision and hearing. All participants had English language skills at or above the normal range for their age based on their age adjusted standard scores on the Peabody Picture Vocabulary Test (PPVT-IV; Dunn & Dunn, 2007). For children to be classified as monolingual, parents had to report no more than 20% exposure to a second language. No monolingual children were reported to have more than 10% exposure to any language other than English. The mean reported proportion of exposure for monolingual children was 3.2%, and the median value was 1.5%. For children to be classified as bilingual, parents had to report at least 25% exposure to each language for a continuous period of at least one year (Pearson, Fernandez, Lewedeg, & Oller, 1997). The two language groups were matched on measures of age, socioeconomic status, language skills, and working memory.

Measures

Background questionnaire. Parents completed a form providing detailed information about the child’s age, gender, ethnic and language background, and parents’ education. The language portion included age in months of first exposure to each language and percentage of exposure to each language. The questionnaire also included questions regarding the child’s health and development to ensure that children had no conditions that would affect the outcome of the study.

Language skill. All children took the Peabody Picture Vocabulary Test, Fourth Edition (PPVT-IV; Dunn & Dunn, 2007), which measures receptive vocabulary in English. In this task, children are given a series of four-choice alternative picture pages. For each page, the experimenter says a word and asks the child to point to the picture that best represents that word. There are 228 total items on the PPVT. Test words start very simple, graded for the participant’s age (e.g. “peeking,”), and gradually become more difficult (e.g. “constrained,”). Children begin testing in a block of 12 words appropriate for their age range, and they continue until they make errors on at least 8 out of 12 words in a single block. Standard scores are calculated based on age norms, with a mean of 100 and standard deviation of 15.

Working memory measures. Past studies on bilingual cognitive development have suggested a lack of bilingual advantage due to working memory differences between samples, or a bilingual advantage specific to working memory and not encompassing other cognitive processes (Namazi & Thordardottir, 2010; Engel de Abreu, 2011; Blom, Küntay, Messer, Verhagen, & Leseman, 2014; Morales, Calvo, & Bialystok, 2013; Bialystok, Poarch, Luo, & Craik, 2014). To address this issue, we tested children on verbal and nonverbal working memory measures to better control for these factors that could affect bilingual advantage.

Nonverbal working memory. Participants completed a *Complex Spatial Recall* task to measure nonverbal WM in a visuospatial modality (Cirino, 2011). In this task, children viewed a series of 2x2 matrices containing either a star or a novel image in one quadrant of the matrix, printed in black-and-white. Each matrix was presented individually on one sheet of 11" x 8.5" landscape-oriented paper, kept in order in a binder. For each matrix, children judged whether or not the item is a star by saying "yes" or "no." After viewing a series of matrices, participants were shown a blank matrix and asked to point to the quadrants where each image was located, in the order that they were presented. Children were given two practice trials, with two matrices each. Children were given feedback on the practice trials. The experimenter repeated incorrect practice trials as needed, to demonstrate the correct answer, and to allow the child to repeat that trial. Test trials began with a series of two matrices and continued up to five matrices, or until the child gave incorrect responses for every trial of a given series length. Three trials of each series length were given. Correct responses had to have the correct order of the quadrant location for every item of the series, with no additional items. Unbiased encouragement, but not feedback, was given during the test trials. Nonverbal WM scores were calculated as total correct responses, with a maximum of twelve points possible.

Verbal working memory. Participants completed a Complex Word Recall task to measure verbal WM, using a modified version of the Word Recall test from the Automated Working Memory Assessment (AWMA; Alloway, 2007). In this task, the experimenter presented participants with series of words increasing in length from one to five. For each word, children were required to judge whether the item was alive by saying “yes” or “no.” After each series, children were asked to repeat all of the words from that series in the same order as they were presented. Two practice trials were given for series lengths of one, two, and three words. Feedback was given only during the practice trials. Additional practice was provided if children responded incorrectly to the first two practice trials. Correct responses required participants to give every word in the series, in the correct order, with no additional words. Six trials were given for each series length. Testing ended when a child gave three or more incorrect responses within a given series length. Verbal WM scores were calculated as total correct trials, with a maximum of 30 points possible.

Cognitive control tasks. The Dimensional Change Card-Sorting task (DCCS; Frye, Zelazo, & Palfai, 1995) was used to assess cognitive control. Each child was tested on three modified DCCS conditions as detailed in the following subsections (see Figure 1 for a brief summary of the stimulus presentation in the conditions). Before beginning testing, children were familiarized with all the images that were used for DCCS during a matching game. Using white cards printed on one side with two copies of each image used in the experiment, children flipped over cards to find identical images. The experimenter asked the child to identify the name and color of each familiar matching pair and to sort the pairs into piles of familiar foods, familiar animals, and novel shapes. The experimenter corrected and reinforced any responses that did not match the labels or categories that would be used during computerized testing.

Nonsemantic (novel shape) condition. In the *Nonsemantic* condition, children were presented with only visual input. They were required to sort objects according to shape and color, similar to the standard DCCS task (Frye, Zelazo, & Palfai, 1995). The shape condition used novel shapes and non-cardinal colors in order to eliminate semantic value from the input (see Appendix for all DCCS stimuli). Children were required to sort these items using only the basic visual information of shape and color without any semantic representations or corresponding spoken linguistic input.

Visual (semantic) condition. The *Visual* DCCS condition used meaningful images of brown and green animals and food items that are semantically linked to their respective colors. For this and the following two semantic DCCS tasks, children sorted by category (“kind”) and color. Stimuli in this task were labeled during familiarization. However, these items were presented only visually during practice and testing so that children had visual information and semantic representations but not any corresponding spoken linguistic input.

Visual + Spoken (semantic) condition. The *Visual + Spoken* DCCS condition used a different stimuli set of the same semantic categories and colors. Stimuli in this task were presented visually and also given a spoken label during practice and testing, as well as during familiarization. Children therefore had the maximum input for these items, with visual information, semantic representations, and corresponding spoken linguistic input.

Procedure

Each child participated in one session lasting 1-2 hours. Play breaks were given if needed when children were too tired or fussy to continue. At the beginning of the session, the experimenter explained the procedure and allowed time for questions from both the parents and participants. Then parents provided informed written consent, and children provided informed verbal assent to participate. Parents also completed the language background and socioeconomic status (SES) form.

Tasks alternated so that after each DCCS condition, a non-computerized task was performed. After the first DCCS condition, children were given PPVT-IV. After the second and third conditions, they completed the nonverbal and verbal WM tasks, respectively. The order of the semantic DCCS conditions was balanced between participants. The Nonsemantic task, because it required sorting by “shape” instead of by “kind” was counterbalanced to be either first or last, to lessen confusion due to switching back and forth between semantic and nonsemantic sorting in different tasks.

All experimental tasks were completed in a quiet room in a laboratory setting with minimal distractions. Children completed the DCCS conditions on a desktop touchscreen computer. All visual stimuli were presented on a white background. All auditory stimuli were recorded by a female native English speaker and played through the computer speakers. Labeled visual stimuli appeared simultaneously with spoken word onset. The stimuli for all DCCS tasks were familiarized in a matching card game before the start of testing. Familiarization ensure that every child understood the semantic value of each stimulus. Nonsemantic stimuli were familiarized only with a general acknowledgement, such as, “That one’s a funny shape.” All semantic (food and animal) stimuli were familiarized by asking the child to give their names.

During computerized sorting trials, two visual targets were presented on either side of the top half of the screen. For the duration of each condition, the two targets remained the same. Visual sorting stimuli appeared in the center of the bottom half of the screen, and auditory stimuli were played through the computer speakers. Two sorting stimuli were used in each condition, which were both similar to each visual target on exactly one dimension. Children sorted stimuli by touching the appropriate target on the screen. Before each DCCS block, children practiced sorting each stimulus twice according to the instructed sorting rule. Within each condition, stimuli were counterbalanced so that each stimulus was a target for half of the participants and a sorting stimulus for the other half. The stimulus sets (see Appendix) were balanced in the semantic conditions, so that sets of foods and animals appeared in different conditions across participants.

Each DCCS condition consisted of 3 blocks, with the third being the test block. The first two blocks were *invariant*, so that each trial followed the same sorting rule. These two blocks were *preswitch* and *postswitch*, which each consisted of 6 trials. The number of trials was based on standard protocol for the DCCS task (Zelazo, 2006). Invariant blocks were balanced within participants such that for each participant, color was the sorting rule in the preswitch block on half the tasks and in the postswitch phase on the other half; invariant blocks were also balanced within conditions such that for each condition, color was the sorting rule in the preswitch block for half of participants and in the postswitch block for the other half. The test block was *mixed*, so that half of the trials followed one sorting rule, and the other half followed another sorting rule. Mixed blocks each consisted of 12 trials, which were pseudorandomized so that the same type of trial (with the same stimuli sorted by the same rule) could not appear consecutively more than twice. In the mixed block, sorting rules were given according to the color of a box shown around the image (or in place of the image during the Spoken condition). A “colorful red box” always indicated that the stimulus should be sorted by color, and a “plain black box” always meant that the stimulus should be sorted by shape for the nonsemantic condition or kind for the semantic conditions.

Design and analyses

The current study tested for language group differences on DCCS conditions differing in the semantic and linguistic information provided to the participants. The conditions are *Nonsemantic* with novel pictures as visual input, *Visual* with only familiar pictures as visual input, and *Visual + Spoken* with familiar pictures as visual input and familiar spoken labels as lexical input. All participants completed each condition. Within each mixed block, switching occurred between congruent and incongruent trials. Switching cost is discussed as the negative effect that the switching trials (incongruent) typically have on cognitive control performance.

Primary analyses compared mixed block accuracy across task-level language input conditions using 2 (language group) x 2 (or trial type) x 2 (language input) mixed model ANOVAs. Accuracy was measured as proportion correct trials out of 6 on each mixed trial type. Switching cost in accuracy is represented by the difference between accuracy the congruent and incongruent trials. The first analysis compared Nonsemantic and Visual semantic conditions in order to test hypothesis 1, and the second compared Visual semantic and Visual + Spoken semantic conditions in order to test hypothesis 2.

Secondary analyses tested RT as well, with the same 2 (language group) x 2 (or trial type) x 2 (language input) mixed model ANOVAs. In RT analyses, incorrect trials were excluded so no effects of accuracy were confounded with RT results. Responses were not permitted within the first 250 ms of stimulus onset to avoid recording expectant responses. RT was measured as the mean time from target stimulus onset to response for all correct trials on each mixed trial type. Switching cost in RT was represented by the difference between RT on the incongruent and congruent trials.

Results

Descriptive Statistics

Language groups were compared on preliminary measures of age, language skill, and socioeconomic status. Language skill was measured as English receptive vocabulary standardized scores on the PPVT-IV. Socioeconomic status was measured as years of education completed by each child's mother and father. In addition, groups were matched on working memory ability. Nonverbal working memory was measured as scores on the complex spatial recall task. Verbal working memory was measured as scores on the complex word recall task. T-tests showed that groups did not differ on any preliminary or working memory measure (Tables 1 and 2). Since groups were matched on all measures, these were not included in the remaining analyses.

Hypothesis 1: Cognitive control with no lexical input

To test the first hypothesis, a 2 (language group) x 2 (trial type) x 2 (language input) mixed ANOVA was conducted to compare results across the Nonsemantic and semantic Visual task-level language input conditions, which differ only by the semantic value of their visual input. The interaction of language group with language was the effect of interest, but trial type was included as a factor to control for performance differences in switching and non-switching contexts. There was no main effect of language group or trial type, but their interaction was significant ($F=4.38$, $p=0.0439$). Bilinguals did not show significant switching costs between congruent ($M=0.6435$) and incongruent ($M=0.6713$) trials, whereas monolinguals showed a much larger cost between congruent ($M=0.7037$) and incongruent ($M=0.6019$) trials (Figure 2). There were no other interactions. A main effect of task-level language input ($F=20.11$, $p<0.0001$) showed that children are more accurate overall on the Visual semantic ($M=0.7245$) compared to the Nonsemantic ($M=0.5856$) condition.

Since bilingual advantages were expected only in the Nonsemantic condition, we tested a 2 (trial type) x 2 (language group) mixed ANOVA on trial accuracy specifically for the Nonsemantic task. This ANOVA showed no significant main effects. An interaction of language group and trial type ($F=5.11$, $p=0.0303$) showed that monolinguals have a larger switch cost between congruent ($M=0.6296$) and incongruent trials ($M=0.5278$), when compared to bilinguals (congruent $M=0.5556$; incongruent $M=0.6296$; see Figure 2a).

We also conducted a separate 2 (language group) x 2 (trial type) mixed ANOVA on trial accuracy in the Visual semantic condition. No effects of language group, trial type, or interactions were found (Figure 2b).

These results align with the first hypothesis, suggesting that when given semantic visual input with no labels, it is possible the high demands of lexical access eliminate the bilingual advantages in cognitive control.

Hypothesis 2: Cognitive control with lexical input

To test the second hypothesis, a 2 (language group) x 2 (trial type) x 2 (language input) mixed ANOVA was conducted to compare the Visual + Spoken task directly to the Visual semantic task, since these conditions differ only by their lexical input provided. Main effects of trial type ($F=7.4$, $p=0.0102$) and task-level language input ($F=9.1$, $p=0.0048$) were significant. In general, children were more accurate on congruent (0.7119) than incongruent ($M=0.6343$) trials, and they were also more accurate on the Visual ($M=0.7245$) compared to the Visual + Spoken ($M=0.6296$) semantic condition. In these conditions, no effects of language group or any interactions were found (Figure 2).

To ensure that no concealed effects would be found when tested separately, a 2 (language group) x 2 (trial type) mixed ANOVA was conducted on trial accuracy in the Visual + Spoken semantic condition as well. This revealed an effect of trial type (F=7.23, p=0.0110), but no effect of language group or interaction. Again, children were more accurate on congruent (M=0.6852) than incongruent (M=0.5741) trials (Figure 2c).

These results indicate that the addition of the spoken label may not sufficiently help bilinguals to overcome difficulties with language processing in this cognitive control task.

Secondary analyses

To measure processing speed, the same three-factor ANOVAs for each hypothesis were run using reaction time (RT) instead of accuracy as the dependent variable. All incorrect trials were excluded from mean RT calculations, so only differences on correct trials were used in all analyses. Since low trial numbers reduce the reliability of reaction time data, these were included only as additional analyses.

For hypothesis 1, a 2 (language group) x 2 (trial type) x 2 (language input) mixed ANOVA on trial RT, compared processing speed in the Visual semantic and Nonsemantic conditions. In this analysis, the interaction between language group and task-level language input was significant (F=5.09, p=0.0306). In the Nonsemantic condition, monolinguals (M=3099.18 ms) and bilinguals (M=3043.96 ms) did not differ in their reaction times. However, in the Visual semantic condition, bilinguals (M=3498.00 ms) were much slower than monolinguals (M=2518.71; see Figure 3a and 3b).

Finally, for hypothesis 2, a 2 (language group) x 2 (trial type) x 2 (language input) mixed ANOVA on trial RT, compared processing speed on the Visual and Visual + Spoken semantic conditions. An interaction of language input condition with language group was marginally significant (F=3.95, p=0.0549). Bilingual children were slower to respond than monolingual children in the Visual condition, but not in the Visual + Spoken condition (monolingual M=2561.81 ms; bilingual M=2828.51 ms; see Figure 3b and 3c). A main effect of input condition also showed that on average, all children were slower on the Visual condition (M=3008.35) compared to the Visual + Spoken condition (M=2695.16; F=3.05, p=0.0895). This finding provides evidence that the demand for lexical access in the Visual task does give monolingual children an advantage over bilinguals that is lost in tasks that facilitate lexical access through spoken labels or do not require language processing.

Discussion

Cognitive control tasks may differ in difficulty for children based on their semantic or linguistic content. However, few studies systematically manipulate the same test to measure the effects of these forms of input. To examine this question, we compared modified versions of DCCS, providing a way to understand what cognitive and linguistic mechanisms are involved in performing this task.

The goals of the current study were to investigate the important of task-level language input to cognitive control performance for bilingual and monolingual children. We proposed that lexical access is tightly linked to cognitive control performance, causing bilingual advantages to disappear on language-based cognitive tasks. Our first prediction stated that bilinguals would excel at cognitive control in a nonlinguistic context, where no lexical access demands are made, but bilinguals would fail at cognitive control in a semantic context, where lexical access demands are high. Our second prediction stated that bilinguals would regain an advantage in cognitive control when spoken labels were provided to reduce the demands of lexical access.

The first hypothesis predicted that bilingual advantages would be found on the Nonsemantic task, but not on the corresponding Visual semantic task. Results from these two conditions supported this prediction, providing additional evidence for a bilingual cognitive advantage to support previous research from nonlinguistic tasks. Bilingual advantages were prominent in the Nonsemantic task, but not in any semantic condition. Although when comparing across conditions, this interaction was not significant, these findings still show that bilingual advantages are more likely to be found in a nonlinguistic test of cognitive control. In the Nonsemantic task, bilinguals performed even better in a switching context than in a non-switching context, indicating that the bilingual language experience may make switching even easier for bilingual children than keeping the same rule. This could mean that bilinguals expect to switch rules more often, and so they are more prepared to switch than to stay with the same rule.

The second hypothesis predicted that bilinguals would also show advantages in a semantic task when provided with both visual input and a spoken label. However, no bilingual advantage was apparent in this task. This suggests that spoken labels may not be sufficient to help bilinguals demonstrate an advantage in cognitive control on the semantic DCCS tasks. However, in partial support of the second hypothesis, monolinguals showed advantages specific to the Visual semantic task. In the Visual condition, bilingual children were slower than monolingual children to process correct responses. Since children performed most accurately in this condition on average, this bilingual disadvantage came as a surprise. However, the richness of the semantic representation most likely contributed to the high average accuracy in this condition, especially compared to the low average accuracy in the Nonsemantic condition, which provided a very shallow perceptual representation of categories. At the same time, this rich semantic representation without any linguistic support may have slowed down bilingual lexical selection. In comparison, since no bilingual disadvantage is found in either DCCS condition with spoken labels, this finding may indicate that spoken labels do aid in lexical access and contribute to bilingual cognitive control.

Implications and future directions

The results of this study help illuminate the language processes influencing cognitive control in both bilingual and monolingual children. In doing so, we provide valuable information to help guide clinical and education practices. Developmental studies of cognitive control have far-reaching applications, including predicting academic achievement. We know from previous work that cognitive control is strongly correlated with academic achievement (e.g. Best, Miller, & Naglieri, 2011). A study by Coldren (2013) tested academic correlates of cognitive control on DCCS tasks. In that study, the language-based task, but not the perceptual task, was strongly related to academic outcomes. In that case, the linguistic task involved reading, which is independently a strong predictor for academic outcomes (e.g., Crawford, Tindal, & Stieber, 2001). Other language skills also contribute independently to academic achievement (e.g., Kastner, May & Hildman, 2001). The current findings present a new view on cognitive control performance based on lexical access demands. The differences in performance in these tasks could be reflected in academic performance, depending on how information is presented in the classroom or in a testing situation. While monolingual children may benefit the most from tasks presented visually, bilingual children may benefit more from tasks presented with labels. Future studies may focus on how these principles may be implemented in mixed language classes with English language learners. In addition, longitudinal studies of cognitive control in monolingual children who are becoming bilingual when they begin formal education could illuminate the developmental patterns of bilingual cognitive control and lexical access.

Conclusions

Past studies have shown that bilinguals have cognitive control advantages in certain nonverbal tasks, but not on various language-based tasks. However, those studies have not established whether this advantage occurs due to the familiarity of visual input, the labeling of familiar objects, or the semantic value of the input. Here, we demonstrate that bilinguals do not show advantages on semantic tasks regardless of visual input or spoken labels, but they do show a disadvantage on a semantic task with only visual input and no spoken label provided to assist with lexical access. These findings lead to the conclusion that the inclusion of spoken labels to facilitate lexical access may at least re-level the playing field for bilingual children on semantic tests of cognitive control.

Tables

Table 1: Sample means for demographic and working memory measures

Total Sample Means (N=36)	Mean (SD)	Minimum	Maximum
Age (mo)	66.9127 (7.3897)	54.90	80.0
Maternal education (yr)	16.6666 (2.4377)	12.0	21.0
Paternal education (yr)	16.7500 (3.2015)	8.0	24.0
PPVT standard score	111.8333 (16.7579)	81.0	150.0
Complex Spatial Recall	5.0000 (3.2950)	0	11.0
Complex Word Recall	10.7222 (3.6064)	5.0	20.0

Table 2: Group means and t-tests for demographic and working memory measures

Group mean differences	Mean (SD)		Two-tailed
	Monolingual (n=18)	Bilingual (n=18)	p-value
Age (mo)	68.7333 (7.4644)	65.0921 (7.0493)	0.1416
Maternal education (yr)	16.5000 (2.5952)	16.8333 (2.3326)	0.6878
Paternal education (yr)	16.0555 (2.6228)	17.4444 (3.6335)	0.1973
PPVT standard score	111.8888 (17.9111)	111.7777 (16.0424)	0.9845
Complex Spatial Recall	5.1666 (3.5686)	4.8333 (3.0917)	0.7664
Complex Word Recall	10.6111 (4.2167)	10.8333 (2.9950)	0.8564

Figures

Figure 1: DCCS conditions

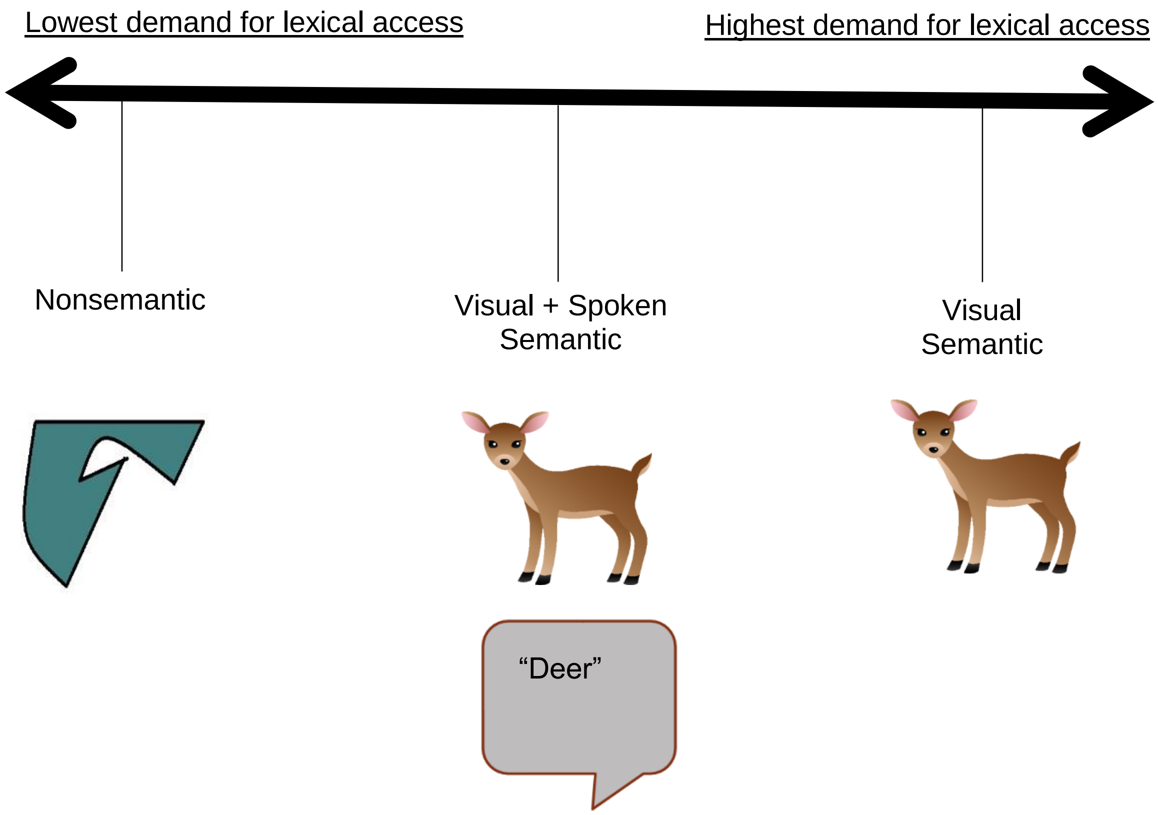
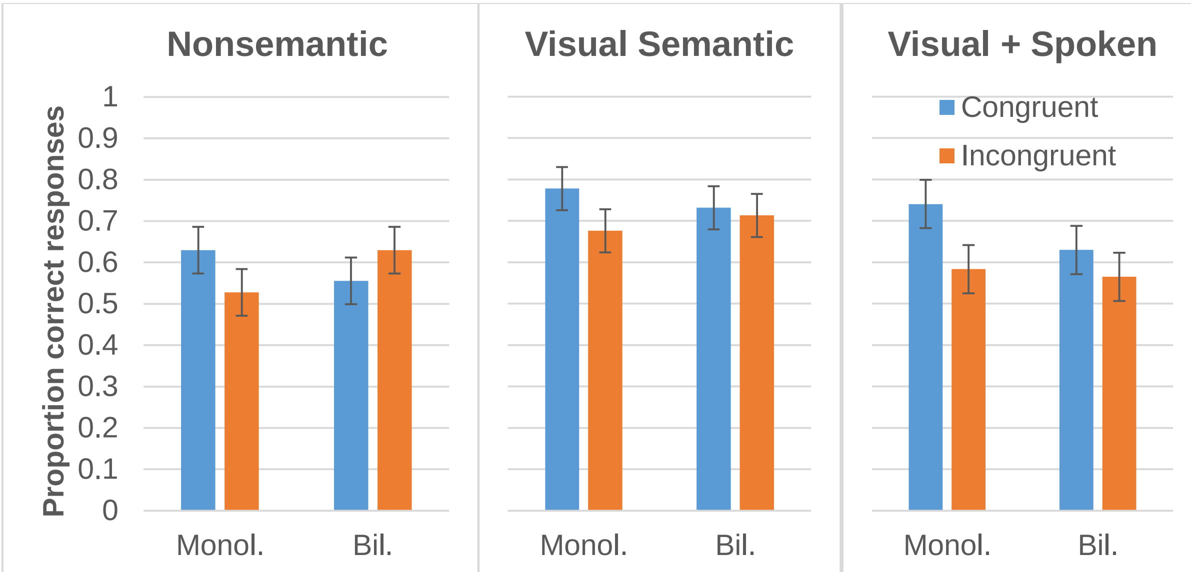


Figure 2: Primary analyses (accuracy)

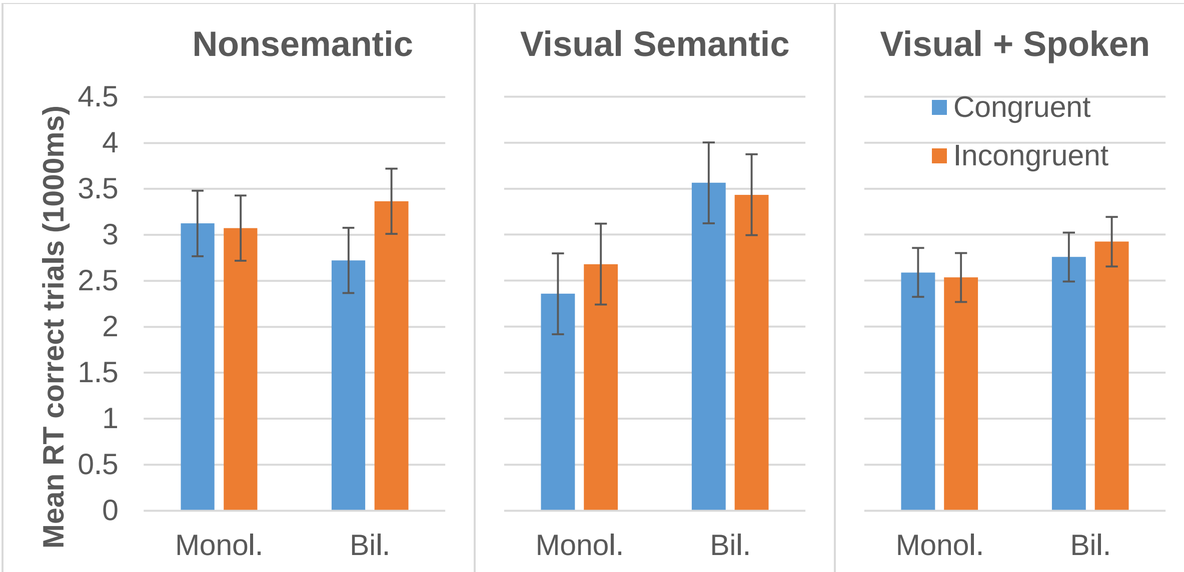
a. Nonsemantic b. Visual semantic c. Visual + Spoken



Bars represent standard error. Monolingual children showed significant switch costs on the Nonsemantic condition (a), but bilingual children did not. Bilinguals did not show advantages on the conditions that required higher lexical access demands (b) and (c). Children showed the largest switch costs on the condition that included spoken labels during semantic sorting (c). Children were most accurate on the semantic task that did not include a spoken label (b).

Figure 3: Secondary analyses (reaction time)

a. Nonsemantic b. Visual semantic c. Visual + Spoken



Bars represent standard error. Bilingual children were slower than monolinguals to respond on the Visual semantic condition (b) compared to the conditions that had low demands for lexical access (a) and (c).

Appendix

Sets of test stimuli used for modified DCCS tasks

All foods and animals were chosen from the MacArthur-Bates Communicative Development Inventory (Dale & Fenson, 1996) in order to ensure selection of familiar words that are commonly understood by 5-year-olds. Colored outlines (only in appendix) indicate target pairs (i.e., if the red pair are targets, then the blue pair will be sorted, and vice versa).

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